

CHOICE AND REINFORCEMENT DELAY

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Previous studies of choice between two delayed reinforcers have indicated that the relative immediacy of the reinforcer is a major determinant of the relative frequency of responding. Parallel studies of choice between two interresponse times have found exceptions to this generality. The present study looked at the choice by pigeons between two delays, one of which was always four times longer than the other, but whose absolute durations were varied across conditions. The results indicated that choice is not uniquely determined by the relative immediacy of reinforcement, but that absolute delays are also involved. Models for concurrent chained schedules appear to be more applicable to the present data than the matching relation; however, these too failed to predict choice for long delays.

Key words: choice, delay of reinforcement, matching law, IRTs, concurrent-chain schedules, pigeons

When a reinforcer is delayed, generally it becomes less effective in strengthening or maintaining behavior. The effects of delayed reinforcement have been assessed through a variety of techniques. For example, delays have been studied with concurrent-schedule procedures where the effects due to one delay value can be assessed relative to another delay value. Chung (1965) arranged a two-key concurrent-schedule-of-reinforcement procedure for pigeons under which responding on one key was immediately reinforced while responding on the other key was reinforced after a delay. The overall rates of reinforcement were equated by including blackouts on the immediate-reinforcement key. Chung found that the absolute and relative response rates on the delay key

decreased exponentially with increasing delays; however, the overall response rate for both keys did not change over conditions.

Chung and Herrnstein (1967), in an extension of the above experiment, studied the performance of pigeons under a concurrent variable interval (VI 1-min VI 1-min) schedule arranged as follows: The left key, called a standard key, had an 8-sec delay of reinforcement for one group and a 16-sec delay for a second group. On the right key, called the experimental key, the delays ranged from 1 to 30 sec in different conditions (2 to 30 sec for the second group). Additional blackouts were not scheduled to equate maximum rates of reinforcement as Chung (1965) had done. They found that the relative frequency of responding on the experimental key decreased with increasing delays. Moreover, the relative frequency of responding on the experimental key matched the relative immediacy of reinforcement on the experimental key (immediacy is defined as the reciprocal of delay). In terms of the matching function (see de Villiers, 1977, and Herrnstein, 1970, 1974, for alternative forms and empirical support):

$$\frac{P_e}{P_e + P_s} = \frac{I_e}{I_e + I_s} \quad (1)$$

where P is key pecks, I is immediacy of reinforcement, and the subscripts e and s indicate experimental and standard keys, respectively.

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Chung and Herrnstein (1967) also found that Chung's data (1965) could be incorporated into this matching relation if a functional delay of 1.6 sec were assumed for the nominally immediate reinforcement. This value of 1.6 sec does not necessarily mean that it takes the pigeon 1.6 sec to get to the feeder from the key; it could partially reflect a decrease in the magnitude of the reinforcer since some unknown portion of access to grain is lost in the transition from pecking to eating (Chung & Herrnstein, 1967; cf. de Villiers, 1977). Since magnitude of the reinforcer is known to affect choice (Catania, 1963; Neuringer, 1967), the 1.6 sec could represent the delay equivalent of that loss in magnitude combined with the transition time from the key to the feeder.

Herbert (1970, Exp. III) replicated the Chung (1965) procedure with the additional restriction of equalizing reinforcement for responding on the two keys. On one key reinforcement was nominally immediate, and on the other key the reinforcers were delayed 0, .2, .5, 1, 3, 15 sec across conditions. The data were then analyzed using the procedure suggested by Chung and Herrnstein (1967); i.e., the nominally immediate reinforcement was assumed to have a functional delay of 1.6 sec. Herbert did not find matching.

There appears to be a problem with Herbert's analysis of this experiment. The greatest deviations from matching occurred at relative immediacies of reinforcement exceeding the value of .50. But these values imply that nominally delayed reinforcement was more immediate than nominally immediate reinforcement. If there is some real delay and loss of magnitude of the reinforcer operating with the nominally immediate reinforcement, it must be assumed to operate on both keys. For example, under the condition with the delay key associated with a 0-sec delay, Herbert used 1.6 sec for the standard key delay and 0 sec for the delay key, when in fact both keys were operating identically. Thus, the condition with relative immediacy of 1 should have a value of .5. Similarly, the conditions with delays of .2, .5, and 1 sec may be interpreted differently, but the values for $I(e)$ that should be used are not intuitively obvious. As the delays increase from 0 to 1 sec, the potential loss in magnitude of reinforcement decreases and the real delay increases.

Results similar to those of Chung and Herrnstein (1967) have been found in studies of choice between interresponse times (IRTs). Shimp (1968) arranged a concurrent paced-VI paced-VI schedule of reinforcement wherein responses that fell into one of two IRT classes were reinforced under a VI schedule. Shimp found that an IRT could be considered as an operant in that the relative frequency of an IRT varied as a function of the reinforcement parameters known to affect concurrent responding. However, the temporal parameters of the IRTs were superimposed on these functions, since the shorter IRT was more preferred. By using the analogy of an IRT being equivalent to a delay of reinforcement, Shimp (1969) found that the relative frequency of an IRT matched the relative reciprocal of the short IRT. This relationship is analogous to Chung and Herrnstein's formulation of matching to relative immediacy of reinforcement.

The matching relation for IRTs has subsequently been shown to be restricted by certain variables. Shimp (1970) found that at low overall reinforcement rates matching does not occur. The study by Chung and Herrnstein (1967) involved rather high reinforcement rates (maximum of 120 per hour), and therefore they probably did not encounter this problem. Hawkes and Shimp (1974) found that the absolute durations of the IRTs also influenced the preference measures away from matching: with short IRTs (high response rates), there was little preference; with long IRTs (low response rates), preference for the shorter IRT exceeded the matching value. Although it is questionable to compare absolute delays and absolute IRT durations, the values of delay as used by Chung and Herrnstein (1967) were not extremely long or short.

The present study was designed to test matching to relative immediacy of reinforcement as found by Chung and Herrnstein. Hawkes and Shimp (1974) found that the absolute values of the IRTs over a large range were important determinants of choice. The present study followed a similar procedure to determine if absolute delays were also important. The relative immediacy of reinforcement on the short-delay key was held constant at .80 (i.e., one delay was always four times longer than the other), and absolute delays were varied across conditions. If relative immediacy of reinforcement is the primary or

overriding factor in choice determination, the relative frequency of responding should follow the matching value at .80. However, if absolute delays are also important factors, deviations from matching should occur at short or long delays, as would be predicted from the results of Hawkes and Shimp.

METHODS

Subjects

The subjects were four male White Carneaux pigeons (P3, P6, P51, and P74) maintained at approximately 80% of their free-feeding weights. Each of the subjects had previous experience in various operant conditioning experiments.

Apparatus

A chamber (36 cm by 36 cm by 36 cm) similar to that of Chung and Herrnstein (1967) was used in the present experiment. The chamber contained two response keys mounted 9 cm apart, each requiring a minimum force of .1 *N* to operate. Key operation provided auditory feedback. A feeder that allowed 3-sec access to mixed grain was located midway between the two keys and 20 cm below them. For the first three conditions and part of the fourth, the chamber was illuminated by a 6-W white light except during blackouts and feeder operation. Due to repeated lamp failures, the light was not used in the remaining conditions. The response keys were transilluminated by red lights (General Electric, number 1829) except during blackouts and feeder operation. Masking noise was present throughout the experiment. The programming and recording of events were controlled by electromechanical devices in an adjacent room.

Procedure

Food was made available on a variable-interval (VI) 1-min schedule on each key with a 1-sec changeover delay (COD); i.e., a reinforcer followed the first occurrence of a response on a key after 1 min on the average, provided that at least 1 sec had elapsed since responding changed to that key. Reinforcement frequency and overall rates of reinforcement were equated for the two keys. In all conditions other than baseline (Conditions I and III), reinforcement was delayed four times longer on one key than on the other; i.e., the

Table 1
Sequence and Parameters of Experimental Conditions

Condition	Session duration (hr)	Left-key delay (sec)	Right-key delay (sec)	Reinforcement sequence (sec)
I	1	1	1	4
II	1	1	4	7
III	1	1	1	7
IV	1	8	2	12
V	1	4	16	21
VI	1	32	8	37
VII	1.5	16	64	72
VIII	2	128	32	137
V R	1	4	16	21.5
IV R	1	8	2	12.5
II R	1	1	4	9

relative immediacy of reinforcement on the short-delay key was .80 in all experimental conditions. The sequence and parameters of the conditions are given in Table 1. The short-delay key was alternated between the right and left keys to prevent sequential development of position bias. Since it was deemed necessary to increase delays gradually to maintain responding (Ferster, 1953), several conditions were replicated to assess possible sequential effects.

Stability of responding. Each of the conditions remained in effect until responding remained stable for 5 consecutive days or until it appeared that responding would not stabilize. Stability was determined by (a) visual inspection of cumulative records for stable rates on the two keys within sessions, (b) low variability in the number of responses emitted per session for the last five sessions, and (c) the relative frequency of responding on the short-delay key for each of the last five sessions being within $\pm .05$ of the mean for the last five sessions.

Concurrent VI, VI programmer. The effects of delay of reinforcement found by Chung (1965) and Chung and Herrnstein (1967) were confounded with the relative frequency of reinforcement (Herbert, 1970). This confounding resulted from the use of two independent VI programmers, one for each key. Thus, the relative frequency of reinforcement depended on responding and generally was not .50. To eliminate this confounding and to maintain a VI 1-min schedule associated with each key, a single VI 30-sec tape was used. When the VI 30-sec tape made food available, a variable ratio programmer assigned that reinforcer

either to the left or to the right key in an equiprobable, quasi-random fashion. Once the VI programmer made a reinforcer available, it did not operate again until after the reinforcer was presented. Thus, if a reinforcer were available on the left key, responding on the right key had no scheduled consequences. The net result of this procedure was that a VI 1-min schedule was associated with each key and reinforcement occurred equally often for both keys, regardless of responding.

The VI 30-sec tape contained 25 intervals ranging from 4 to 121.8 sec with an arithmetic mean of 30 sec. The interval values were derived from a formula given to Catania and Reynolds (1968) for approximating an equal probability of reinforcement with respect to time.

Reinforcement sequence. The overall rates of reinforcement were equated for the two keys by manipulating the duration of the reinforcement sequence for the two keys. When food became available on a key, the VI programmer stopped, and the next response on that key that satisfied the changeover delay requirement automatically initiated the reinforcement sequence. The sequence comprised a delay period, followed by a 3-sec feeder operation, followed by a timeout. The delay period was associated with a blackout of the keylights and houselight (when applicable); responding during this period had no scheduled consequences. The timeout following the reinforcer presentation was a continuation of the blackout. At the end of the timeout, the keys and houselight (when applicable) were reilluminated and the VI programmer began operating again.

Under all conditions, the total duration of the reinforcement sequence (delay time + 3-sec access to grain + timeout) was identical for both keys. Under the experimental conditions, when the delay was longer on one key than on the other, the timeout on that key was shorter by an equivalent amount. Thus, the overall rates of reinforcement were equal for both keys. The duration of the reinforcement sequence for each condition is given in Table 1.

RESULTS

Among the data recorded were (a) the number of reinforcers obtained by responding on

each key; (b) the number of responses made on each key; (c) the time allocated to responding on each key, which included time during reinforcement and the changeover although these values were then subtracted for the remainder of the analyses; and (d) the number of changeovers from one key to the other. The data from the last five sessions under each condition are summarized in Table 2 for each pigeon.

P51 did not stabilize under Condition VI after 51 sessions, and P6 did not stabilize under Condition VIII after 31 sessions. Therefore, rather than further increasing the delays, replications were begun for these subjects.

Relative Frequency of Responding on the Short-Delay Key

The relative frequency of responding on the short-delay key is shown in Figure 1 as a function of the short delay. The dashed line in Figure 1 is the matching value of .80 that would be predicted from the model (Equation 1) proposed by Chung and Herrnstein (1967). Clearly, these data do not fall along the matching value of .80. Only in the mid-range of delays used did the relative frequency of responding on the short-delay key approximate the matching value. For shorter and longer delays, the degree of preference was lower than .80.

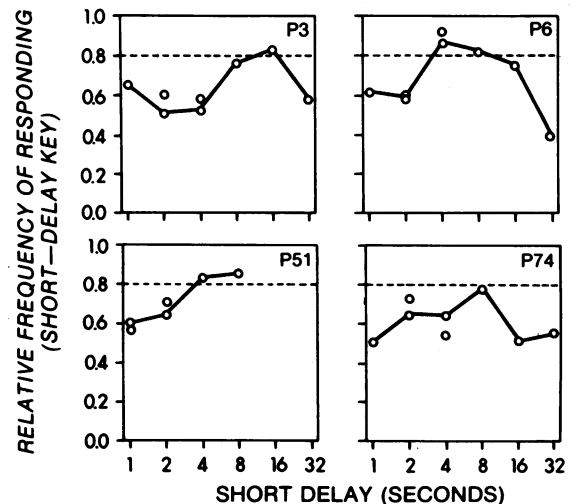


Fig. 1. Relative frequency of responding on the short-delay key as a function of the short delay. The dashed line indicates the prediction from Chung and Herrnstein (1967). The unconnected data points represent the replication values. The data at the longest delay for P6 and P51 do not represent stable values.

Table 2

Summary of the data for each pigeon. The entries are totals for the last five sessions for each condition. (*) indicates responding was not stable for that condition. "R" indicates replication.

Pigeon	Condition	Number of sessions	Responses		Time spent (sec)		Change-overs	Number of reinforcements
			left	right	left	right		
3	I	22	10566	10535	9335	12841	2091	383
	II	22	13449	7085	10442	11506	2276	435
	III	32	14068	9180	11020	11082	2239	455
	IV	32	8545	8904	9540	11673	1857	394
	V	18	7394	6630	10136	10132	1261	330
	VI	36	2754	8907	6636	12626	597	232
	VII	24	12682	2572	16294	11974	572	233
	VIII	32	2722	3792	16357	20360	343	191
	V R	19	11154	7935	10829	9974	1309	331
6	IV R	9	8235	12755	7856	13011	1345	389
	I	30	7583	7422			3797	438
	II	21	11842	7343			5133	450
	III	32	13014	7834			4778	453
	IV	32	6407	9227			3129	385
	V	18	15980	2434	13718	5637	705	302
	VI	35	1993	9322	6479	12628	625	235
	VII	24	9606	3183	16190	11848	521	250
	VIII*	31	2919	1904	17378	16835	269	174
51	V R	17	15790	1344	14392	4320	369	272
	IV R	26	8060	12354	8827	12658	1667	391
	I	30	14469	12695	11730	9708	1630	469
74	II	22	24661	16315	12815	8555	1787	461
	III	32	26897	19753	11314	11008	2362	442
	IV	32	10076	18423	5799	13955	1071	375
	V	18	10633	2140	14229	5218	661	246
	VI*	51	756	4462	3425	14762	163	132
	IV R	19	21382	8935	13774	7396	1261	377
	II R	24	16019	21130	8016	12802	1319	419
	I	22	5229	9175	9434	11355	1414	437
74	II	21	9046	8790	9924	10649	1447	433
	III	32	4222	7348	8828	11604	1297	407
	IV	32	4639	8687	7361	12374	1066	375
	V	18	5786	3196	10959	8597	718	311
	VI	35	1830	6471	6794	12073	407	237
	VII	24	2767	2601	13824	13906	348	229
	VIII	32	2206	2753	16992	19513	264	186
	V R	17	3419	2815	9222	10256	692	303
	IV R	11	2571	6797	7032	12401	673	361

Position bias was evident from the data shown in Figure 1. The clearest case of bias was for P74. The up-and-down pattern in the figure corresponds to the change in the short-delay key between the left and right positions. Throughout the study, P74 showed a bias toward the right key.

Time Allocation and Local Rates of Responding

By using the time allocated to each key ("Time Spent" in Table 2), two other measures of preference were obtained: relative time allocation to the short-delay key and rela-

tive local response rate on the short-delay key.

The relative time allocation on the short-delay key is the percentage of time during which the keylights were illuminated that responding was occurring on the short-delay key. These data were very similar to the data for the relative frequency of responding shown in Figure 1. The data for P6 are not available for Conditions I through IV because its high changeover rate made it impossible to record the time allocation accurately.

The local rate is the response frequency divided by the time spent responding. These local rates of responding are plotted in Figure 2

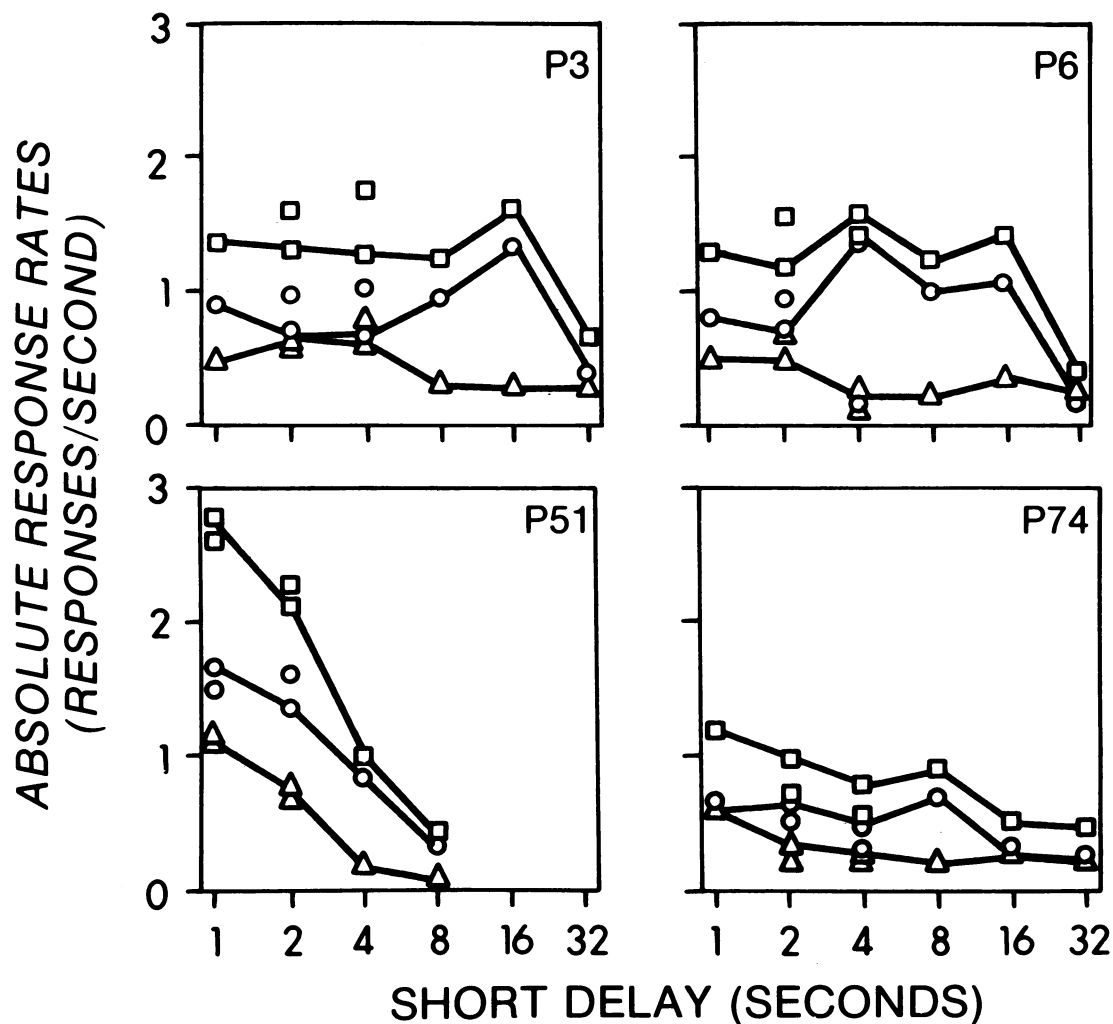


Fig. 2. Local response rates on both keys as a function of the short delay. The circle and the triangle represent the short- and long-delay keys, respectively. The unconnected data points represent replication values. The data at the longest delay for P6 and P51 do not represent stable values.

for both keys as a function of the short delay. The local response rates were very similar with no systematic differences between the keys. There was a slight decline in the local rates as the delays increased (except for P51, which had a sharp decline). Since there was little difference in the local rates of responding for the two keys, the relative local rate of responding on the short-delay key was approximately .50 for all conditions.

Conventional Response Rates

The conventional method for calculating response rates for concurrent operants is to divide the number of responses by the session

duration (Catania, 1966). Because a considerable portion of each session was consumed by delays and timeouts, this procedure was modified to use keylights-on time rather than session duration. The response rate on the short-delay key was higher than the response rate on the long-delay key under all conditions when responding was stable (which reflects the fact that the relative frequency of responding on the short-delay key was greater than .50).

The total response rate was relatively stable with increasing delays, with the following exceptions: P51's rate decreased sharply as the delays were increased, and P3's and P6's rates decreased considerably under Condition VIII.

This general stability in total response rate was anticipated from previous experimental data (Chung & Herrnstein, 1967; Chung, 1965; Ferster, 1953; Nevin, 1974). The effect of Condition VIII on total response rate will be discussed further in a later section.

Cumulative Records

The response patterns that were engendered by the experimental conditions can be typified as a response run on one key followed by a response run on the other. Cumulative records that are representative of the last five sessions for Conditions II, IV, V, VI, and VII for P6 are shown in Figure 3.

These cumulative records show the change in the relative frequency of responding on the short-delay key as a function of increasing delays. As the delay value increased, the rate of responding on the short-delay key increased, then decreased, whereas the rate of responding decreased, then increased on the long-delay key. Thus, the relative frequency of respond-

ing on the short-delay key increased, then decreased, with increasing delays.

Obtained Reinforcement Rate

As the delays increased, an increasing portion of each session was consumed by longer reinforcement sequences. Thus, the overall rate of reinforcement (number of reinforcers per hour), both maximum and obtained, decreased as the delays were increased. The maximum and obtained reinforcement rates are plotted in Figure 4 as a function of the short delay.

In general, the pigeons responding was "efficient" in that the obtained reinforcement rate was a high percentage of the maximum reinforcement rate even at the longer delays. The obvious exception is P51: as the delays increased, the percentage of the maximum that it obtained decreased.

Since the obtained reinforcement rate decreased with the longer delays, it could potentially interact with delays as a codeterminant of choice. Shimp (1970) found that at overall reinforcement rates below about 30 per hour, the relative frequency of the shorter IRT did not match the relative reciprocal of the shorter IRT. The dashed line in Figure 6 represents this value of 30 reinforcements per hour. When the obtained reinforcement rate is below this line, the response pattern may be governed by the reinforcement rate rather than by the delays. The low rate of reinforcement under condition VI for P51 was a possible cause for, and certainly the result of, the unstable low response rate. Likewise, the decline in response rate for P6 under condition VII might have been the result of the low reinforcement rate. However, unlike P51, the low response rate did not cause the low reinforcement rate, since their "efficiency" was still very high.

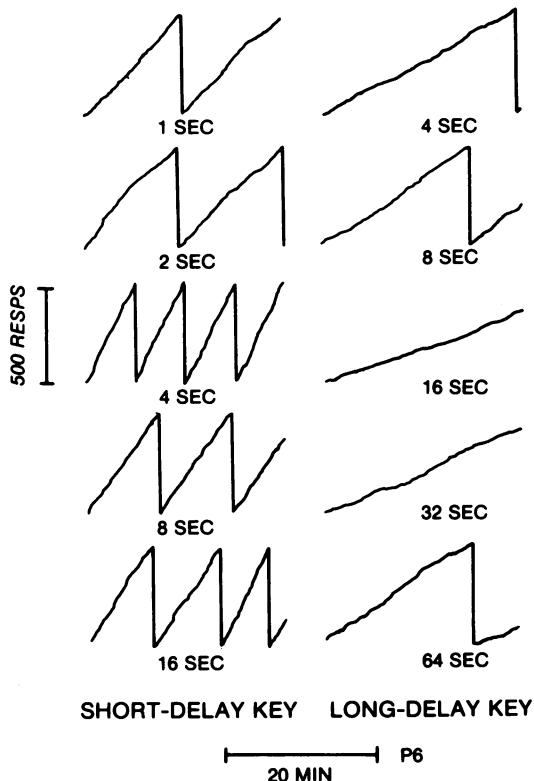


Fig. 3. Cumulative records of responding for P6 under Conditions II, IV, V, VI, and VII. These records are typical of the last five sessions for each condition.

DISCUSSION

The results of the present experiment clearly indicate that the relative frequency of responding on the short-delay key did not match the relative immediacy of reinforcement for all values of delay. Thus, the absolute values of delays were important determinants of choice; that is, if one were to extrapolate to other values of relative immediacy, the degree of preference would be lower than the matching

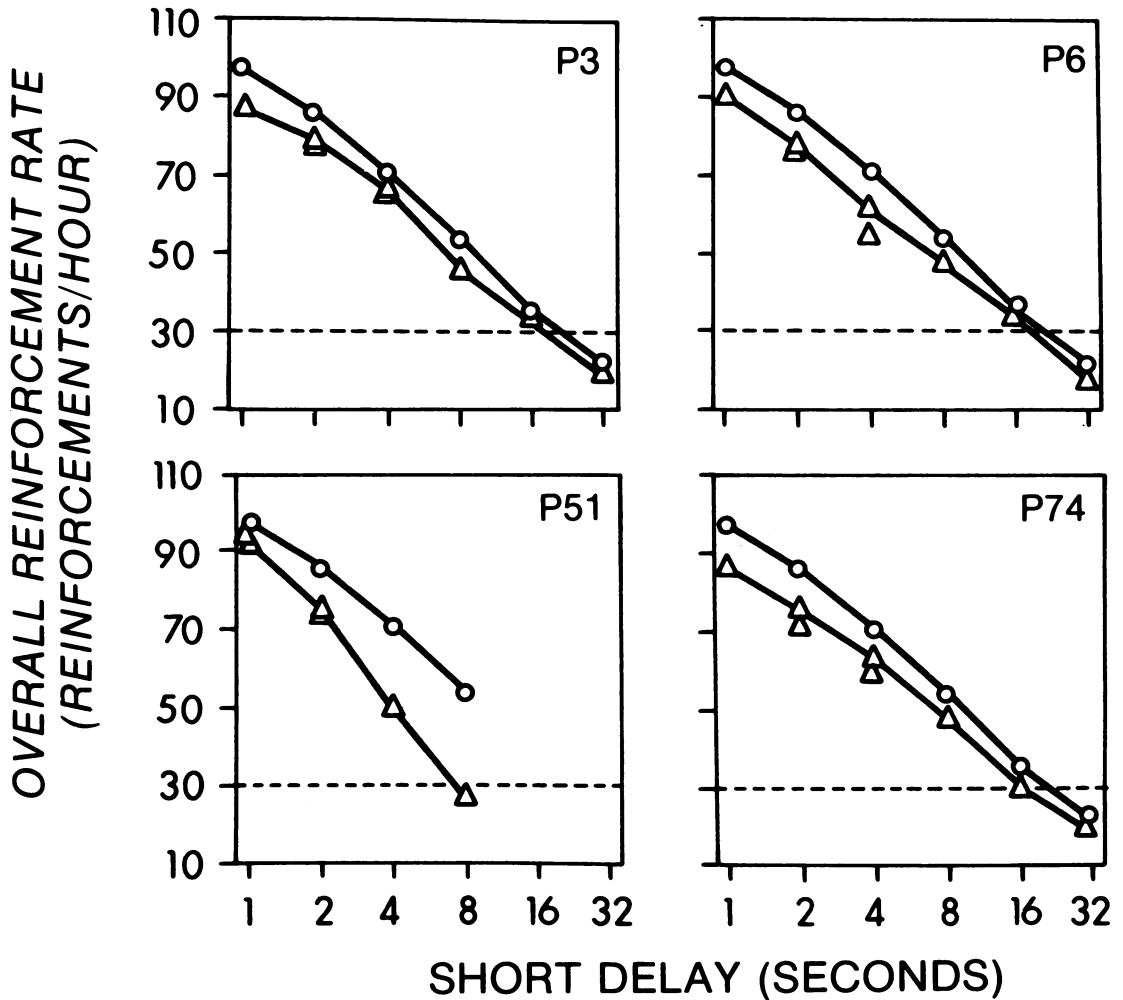


Fig. 4. The maximum and obtained overall reinforcement rate as a function of the short delay. The circle and triangle represent the maximum and obtained reinforcement rates respectively. The unconnected data points represent replication values. The data at the longest delay for P6 and P51 do not represent stable values. The dashed line indicates the reinforcement rate below which Shimp (1970) found no matching.

value if the absolute delays were very short or very long.

Implications for IRT Theories

Since Shimp (1969) found that the same matching function held for IRTs and delays, he concluded that the two might have similar properties. An exception was found for the IRT matching relation (Hawkes and Shimp, 1974) in that matching was a special case of the absolute duration of the IRTs. At the time, this lack of matching represented a breakdown in the analogy; however, the present data indicate that the matching relation

for delays is also a special case of the absolute delay values.

Extending the analogy further is not presently possible. The present data cannot be directly compared to those of Hawkes and Shimp (1974) because there is no known function to relate delay value to IRT value in absolute measures. How short must a short delay be to be equivalent to a short IRT? How long must a long IRT be to be equivalent to a long delay? It is possible that the relative frequency of the short IRT might have decreased had longer IRTs been studied by Hawkes and Shimp. Thus, the question of

whether IRTs are analogous to delays is yet unresolved.

Timeout Procedure

In order to eliminate the known effect of differential reinforcement rates for the two keys when the delays differed, a timeout was in effect following the grain presentation. The timeout duration was adjusted so that it was longer after a short-delay reinforcement by an amount equivalent to the difference in delays. While this procedure did equate the obtained reinforcement rates for responding on the two keys, it introduced two possible confounding variables. As the delays were increased, the reinforcement sequence and the postreinforcement timeouts became longer also. If these two variables were to operate in this experiment, the effects would show at the longer delays.

However, since the total response rate was, in general, relatively unaffected by the increasing delays, and, therefore, decreasing reinforcement rate, it is possible that overall reinforcement rate did not affect choice. The sharp decline in total response rate of P6 and P3 under condition VIII may be due, partially or totally, to the low obtained reinforcement rate. There is no readily apparent explanation for the decrease in total response rate of P51 other than extreme sensitivity to overall reinforcement rate.

It is difficult to see how the postreinforcement timeout could directly influence choice behavior since its effects should be greatest when the delays are longest and since it follows a reinforcer. However, it could operate indirectly by modifying the efficacy of the reinforcer that it follows. That is, two identical reinforcing stimuli could have different reinforcing properties if they were followed by timeouts of different durations. If this were the case, it might be expected that there would be a decline in the local response rate on the short-delay key as delays were increased. As shown in Figure 2, this did not occur.

While response rate measures indicate little influence of these variables, it does not necessarily preclude the possibility of influence on choice measures.

Reformulation of the Experimental Procedure

Traditionally, delay of reinforcement has

been considered a parameter of the reinforcer. However, delay of reinforcement may be more appropriately thought of as a schedule of reinforcement (de Villiers, 1977). The procedure of this experiment was presented in terms of conc VI 1-min VI 1-min schedule with delays of reinforcement. Since the delay was scheduled so that reinforcement followed the to-be-reinforced response by a fixed time regardless of behavior during that time, the delay procedure was a fixed time (FT) schedule. Also, since the two VI 1-min schedules were concurrently available and there was a stimulus change associated with the onset of either FT schedule (the keys became dark), the schedule may be described as a concurrent chained schedule [VI 1-min, FT $d(s)$] [VI 1-min, FT $d(l)$], where $d(s)$ and $d(l)$ are the short and long delays, respectively. The preference for $d(s)$ over $d(l)$ is the relative frequency of responding during the initial link of the VI 1-min associated with $d(s)$. These data are presented in Figure 1.

The advantage of considering the present experimental procedure as concurrent chained schedules is that predictive models for choice, other than that of Chung and Herrnstein (1967), are available for comparison with the present findings. None of these concurrent chained models was specifically designed or empirically tested when both terminal links were FT schedules (Davison & Temple, 1973; Fantino, 1969; Squires & Fantino, 1971). However, since these models were designed for use with VI terminal links and have been tested with FI terminal links, they might also apply to FT terminal links. Furthermore, Neuringer (1969) found that when the terminal links were FI and FT of equal durations, they were equally preferred (see also a recent study by Williams & Fantino, 1978).

Herrnstein (1964) concluded from experimental data that the relative frequency of responding in the initial links matched the relative rate of reinforcement in the terminal links which were VI and VR schedules. If these data were extrapolated to the case where both terminal links were FT, then the relative rate of reinforcement in the terminal links would be identical to the relative immediacy of reinforcement. Therefore, Herrnstein's (1964) experiment predicted the results of Chung and Herrnstein (1967) by assuming that the delay was a FT schedule and that the model applied

to FT terminals links. The prediction for the present data has already been discussed.

Fantino (1969) stated that Herrnstein's (1964) formulation did not account for the performance under many concurrent chained schedules because it did not include the initial link durations. Fantino's (1969) model applied to the present procedure is

$$\frac{P(s)}{P(s) + P(l)} = \begin{cases} \frac{T - d(s)}{[T - d(s)] + [T - d(l)]} & \text{if } d(s) < T, d(l) > T \\ 1.0 & \text{if } d(s) < T, d(l) > T \end{cases} \quad (2)$$

where P is the number of responses, T is the expected time to reinforcement from the onset of the initial links, d is the expected time to reinforcement from the onset of the terminal links (i.e., delay), s and l are short and long, respectively. In the present experiment, T is $(30 + d(s)/2 + d(l)/2)$ sec.

Squires and Fantino (1971) changed Equation 2 to allow for unequal initial links. Their model applied to the present procedure is

$$\frac{P(s)}{P(s) + P(l)} = \begin{cases} \frac{r(s)(T - d(s))}{r(s)[T - d(s)] + r(l)[T - d(l)]} & \text{if } d(s) < T, d(l) > T \\ 1.0 & \text{if } d(s) < T, d(l) > T \end{cases} \quad (3)$$

and

$$r(s) = \frac{n(s)}{t(s) + n(s)d(s)}$$

$$r(l) = \frac{n(l)}{t(l) + n(l)d(l)}$$

where P is the number of responses, T is the expected time to reinforcement from the onset of the initial links, d is the duration of the terminal links, n is the number of reinforcements per entry into a terminal link, and s and l are short and long. In the present experiment $d(s)$ and $d(l)$ were the delay values; T was $(30 + d(s)/2 + d(l)/2)$ sec; $t(s)$ and $t(l)$ were both 60 sec and $n(s)$ and $n(l)$ were both 1.0.

Another concurrent chained model was proposed by Davison and Temple (1973). This model in terms of the present experiment is

$$\frac{P(s)}{P(l)} = \frac{R(s)}{R(l)} \cdot E \cdot \frac{d(l)}{d(s)}$$

where P is responses, R is the reinforcement rate, E is the ratio of obtained entries to a terminal link to the entries provided by the schedule parameters, d is the terminal link duration plus the duration of the reinforcement,

and s and l are short and long. In this experiment $E = 1$, since reinforcements were equated for the two keys. Therefore,

$$\frac{P(s)}{P(l)} = \frac{[60 + d(l)]}{[60 + d(s)]} \cdot \frac{[d(l) + 3]}{[d(s) + 3]} \quad (4)$$

Applying these models (Equations 1 through 4) to the parameters shown in Table 1, provide the functions shown in Figure 5. The present data are also plotted in Figure 5 as an average for the four pigeons (for clarity of presentation). Clearly, the present data are more in accordance with the concurrent chained schedules of Fantino (1969), Squires and Fantino (1971), and Davison and Temple (1973) than with the matching value (Herrnstein, 1964; Chung & Herrnstein, 1967).

The conclusions that can be drawn from Figure 5 are that delays of reinforcement can be considered as a schedule arrangement and, in particular, the present experiment provides evidence that within certain ranges delays of reinforcement under concurrent schedules of reinforcement are very similar to concurrent chained schedules with variable interval terminal links.

At the longer delays when preference decreased, the present data deviated most from all of the predictive models. Whether the de-

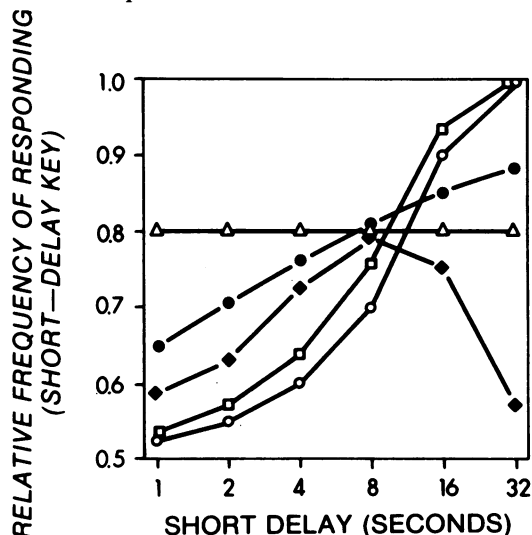


Fig. 5. Comparison of predictive models for concurrent chained schedules with the data from the present experiment. The symbols for the predictive models are as follows: triangle, Chung and Herrnstein (1967); circle, Fantino (1969); square, Squires and Fantino (1972); and filled circle, Davison and Temple (1973). The filled squares are the data obtained in this experiment averaged for the subjects under each condition.

crease in preference was due to decreases in reinforcement rate or terminal link duration, these models should predict the decrease since both of these variables appear in the models (Equations 2, 3, and 4). Picking one model as the best predictor is beyond the scope of the present data since only one parameter (terminal link durations) was manipulated.

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